Impact of logging and forest fires on soil erosion in tropical humid forest in East Kalimantan

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Impact of Logging and Forest Fires on Soil Erosion in Tropical Humid Forest in East Kalimantan

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Abstract

Logging and/or forest fires cause a direct impact of reducing vegetation cover, and in many cases create a pre-condition for the increase of soil erosion rates during high rainfall. Such an increase in soil erosion rate may be higher than the normal threshold rate from a sustainable forest land productivity viewpoint. Field measurement was focused on surface runoff (overland flow) and eroded soil mass on slopes of 25-35% with light and heavy intensities of logging and control plots. Both logging intensities directly increased surface runoff and eroded soil mass, especially on timber felling, skidding trails establishment and log skidding and/or hauling from the logging compartments through feeder roads to the temporary logyard. Higher rainfall amounts and intensity tended to increase the volume of surface runoff and for some cases also eroded soil mass. The volume of surface runoff was 2559 litre ha^{-1} $year^{-1}$; 4711 litre ha^{-1} $year^{-1}$ and 5123 litre ha^{-1} $year^{-1}$; while the cumulative eroded soil mass was estimated to be 0.073 t ha^{-1} $year^{-1}$; 0.046 t ha^{-1} $year^{-1}$, and 0.060 t ha^{-1} $year^{-1}$ for the light, heavy and control of logging intensities respectively. However, the eroded soil mass in all research plots confirmed that there was no significant relationship between soil erosion rate and logging intensity, and the eroded soil mass was lower than the tolerable/permissible/acceptable soil erosion rate. Therefore, erosion control measures in relation to land productivity after logging and fires do not need to be carried out immediately. Regarding the erosion process, the slope and its length (microtopography) was the most important factor for increasing soil erosion rate. Further, vegetation cover was important in reducing and/or minimising the occurrence of surface runoff and soil erosion.

INTRODUCTION

Background

Forest harvesting can cause unavoidable negative impact to both the biotic and abiotic environment, through damage to residual large trees and other forest plant communities and their natural regeneration, exacerbate surface soil erosion, and change physical soil characteristics. The negative impacts may also appear outside the logged area, e.g. aquatic habitat deterioration, river sedimentation, and degradation of water quality. Each step of logging activities can also cause a range of impacts which may vary in size and duration.

For a long time it has been suggested that there are two kinds of significant change of forest condition related to logging activities i.e., crown cover reduction and forest land compaction due to feeder road construction and temporary and permanent log yards. Reduction of crown cover directly increases the amount of rainfall reaching

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the forest floor and simultaneously reduces rainfall interception. Compaction of forest floor by mechanical log hauling and transportation (tractor, skidder, dozer) creates an increase in surface runoff/overland flow increase as a consequence of reducing infiltration rate and/or its capacities. Under such conditions, the major proportion of rainfall is mostly surface runoff/overland flow because the rainfall intensity is generally much greater than the infiltration capacity. Consequently, the rain drop impact increases the probability of soil detachment and movement. It is also possible that the nutrient cycle of the forest ecosystem will be periodically disturbed by logging activities and their after effects, e.g., soil compaction.

Large-scale forest fires occurred during 1982-1983 in the tropical humid forest areas in Kalimantan causing tremendous damage. Similar forest fires also occurred in 1986, 1991, 1997, and the latest in 1998 which degraded a large forest area and its environment. Ecologically, forest fires caused enormous damage to the vegetation, fauna, soils and aquatic ecosystems. Reduction of vegetation cover and organic material both directly and/or indirectly influence soil characteristics and geomorphic processes due to the loss of soil aggregate stability. Additionally, they increase the probability of greater soil/land erosion. especially in open areas frequently subjected to high rainfall intensity (Sudarmadji 1995).

It is broadly accepted that the most dominant factors affecting soil erosion processes and characteristics are climate (especially rainfall), soil erodibility, topography (length and slope), vegetation cover, erosion control measures, and human activities in land management practice. These factors always interact with each other and simultaneously determine the magnitude of soil erosion rate in a particular landscape (Arsyad 1989).

This study area, Taman Hutan Raya, Bukit Soeharto is representative of tropical humid forest areas with soil erodibility ranging from moderate to high. Using the Universal Soil Loss Equation (USLE), forested area under primary forest, secondary forest, burned forest, *ilalang* land (dominated by *Imperata cylindrica*) and spice plantation, it was found that spice plantation had the highest soil erosion rate. Moreover, Sarminah (1995) using plots of 2.5 m x 20 m in spice plantation, *ilalang* land and logged-over burned forest with 37% of slope found that the potential of soil loss through erosion process was 94.8 t ha^{-1} year^{-1}; 2.3 t ha^{-1} year^{-1} and 4.2 t ha^{-1} year^{-1}, respectively. In an experiment on degraded land rehabilitation after forest fires on steep slopes (>30%), Sudarmadji (1997) using plots 5 m x 20 m found that degraded lands without any vegetation cover can potentially lose around 18.2 t ha^{-1} year^{-1} of top soil. This large loss could be reduced to 5.8 t ha^{-1} year^{-1} by planting *Peronema canescens*, by applying a layering planting technique by dense planting of cuttings to 6.5 t ha^{-1} year^{-1}; while other species with a similar technique reduced the loss to 5.8 t ha^{-1} year^{-1} and 6.7 t ha^{-1} year^{-1}.

Problem Formulation

There are two main considerations in relation to increasing soil erosion rate: (1) logging and forest fires reduce the vegetation cover creating a pre-condition for increased surface runoff/overland flow and soil erosion rate where the quantity and intensity of rainfall is high, (2) higher logging intensities and/or forest fires may directly cause soil erosion to increase to a level greater than permissible/acceptable/tolerable in terms of sustainable forest land productivity. Clarification of these problems is important as they are the basis on which decisions are made on erosion control measures and/or degraded land rehabilitation.

Forest Harvesting and Fires

Harvesting of timber is carried out by logging activities which follow the silvicultural system officially applied in Indonesia. In general, the main activities in forest harvesting are felling, hauling and transportation. Construction of feeder roads, branch roads and also main roads are closely related to land degradation, mainly indicated by increased soil erosion rates. Alleviation of this potential damage should be one of the main targets to achieve sustainable forest land productivity and management of forest areas.

Forest fires in East Kalimantan were initiated by a heavy dry period that made the litter on the forest floor very flammable (Hadi 1983). It has been debated for a long time whether slash and burn agriculture is a major cause of fires in East Kalimantan. However, Soedardjo (1982) and Hadi (1983) suggested that forest workers and others carelessly using fire in the forest might also ignite fires. Many burning coal deposits might also start fires in East Kalimantan. Pritchett (1979) and Soeratmo (1979) classified forest fires as: ground fire, surface fire, and crown fire. Forest fire impacts on the chemical characteristics of soil increasing mineral concentration. Additionally, disturbance of the physical soil characteristics will contribute to soil erosion due to soil disaggregation, organic materials destruction, exposing the forest floor to the direct strike of rain and reducing of infiltration capacity (Effendi 1999).

Purpose of the Study

The study's long-term purpose is to assess the impact of logging and forest fires on soil erosion rates in tropical humid forest areas in East Kalimantan. A part of this study is to determine if the increase of soil erosion rates is above or below the acceptable erosion rate. The results should be an important indicator as to whether erosion control measures and/or land rehabilitation need be carried out during and after logging activities, or after fires in logged over-forest.

Site Description

This research was conducted in Cooperative Research Plots (9 ha) located in Bukit Soeharto Education Forest of Mulawarman University. The 9 x 1 ha plots were established with 3 replications of 3 logging intensities (1) heavy intensity - commercial trees of dbh ≥30 cm were cut, (2) light intensity - commercial trees dbh ≥50 cm cut) and (3) control (no cutting) (Ruslim *et al*. 2000). TAHURA Bukit Soeharto is located at 115º 0'34"-116º 0'054"E and 0º 0'50"-1º 0'04"S at 22-58 m above sea level. The study site is located on a flat plain enclosed by undulating hilly areas with slopes of 25-30% and 5-200 m in length. Annual rainfall is 2002 mm (Toma *et al*. 2000). According to the climate classification system developed by Schmidt and Ferguson (1951), the type of climate is categorised into A type (Q = 12.4%) indicating rainfall distributed throughout the year without a distinct dry period. Mean monthly temperature is 21-27^{0}C with relative humidity 65-90%. In the study site soils are dominated by clay (C), sandy clay (SC), sandy loam (SL) and sandy clay loam (SCL) (Table 1).

Table 1. Soil texture

Solum depth (cm)	Particle fraction content (%)			Texture
	Sand	Silt	Clay	
High intensity				
0-10	68	17	15	SL
10-30	62	17	21	SCL
30-60	47	25	28	SCL
60-100	55	18	27	SCL
Light intensity				
0-10	52	26	22	
10-30	47	24	29	SCL
30-60	41	24	35	SCL
60-100	39	20	41	CL
				C
Control				
0-10	52	22	25	SCL
10-30	48	22	30	SCL
30-60	44	19	37	SC
60-100	21	33	46	C

Source: Effendi (1999)

The latest fires (mid-1997 to 1998) were mainly surface fires which burned over ±80% of the area. However, several dipterocarps resisted forest fires, e.g. *Shorea* sp., *Dipterocarpus* sp., *Dryobalanops* sp., *Eusideroxylon zwageri*, *Dillenia excelsa* and *Diallium indum.* Existing degraded (natural) dipterocarp forest suffered relatively light fire damage and their crowns still shaded the forest floor. Dipterocarp genera/species *Shorea* sp., *Shorea laevis*, *Dipterocarpus* sp., *Dryobalanops* sp. and *Eusideroxylon zwageri* dominate this forest type.

In the early period of this research, which was conducted 10 months after forest harvesting and 4 months after forest fire, the existing natural regeneration was very rare. However, after one month of the research, natural regeneration was spreading fast and after only two months the forest floor was almost completely covered. After four months the vegetation cover was 29.9% with a density of 44 plants 100 m^{-2} and average height of 35.7 cm. The coverage projection is shown in Figure 1 and the debris coverage is in Figure 2.

Methods

There were 9 x 1 ha plots established with 3 replications of 3 logging intensities (1) heavy intensity - commercial trees of dbh ≥30 cm were cut, (2) light intensity - commercial trees dbh ≥50 cm cut) and (3) control (no cutting). Erosion research plots 5 m x 20 m in area were placed in the three treatments. All ERP sites were on sites that suffered severe fires during February - March 1999. The nine plots were enclosed by timber inserted into the soil to about 5cm depth and cemented along the outer side of plots. At the end of the lowest part of the plot was an outlet 15-20 cm wide and 30-40 cm long. Two surface runoff collectors (60 litre capacity) were joined up in the lower part of each plot; the first collector was set higher than the second collector so that if the first collector became full of surface runoff water the surplus would flow into the second collector. Two or three simple rainfall collectors with a diameter of 10 cm and 1m length were placed around the plot.

The main parameters measured in each plot were: eroded soil mass (g), rainfall depth (mm), rainfall intensity (mm hour^{-1}), surface runoff (litre), natural regeneration cover (%), and litter cover on forest floor (%). Eroded soil mass was measured by sampling of soluted particle soils in surface runoff solution in the collector for each rainfall occurrences during 4-5 months of field observation. Vegetation cover percentage, litter position and dominant pioneer plant species were recorded periodically in each plot. Physical soil characteristics were taken from other research simultaneously conducted at the same study site.

Surface runoff (m^3 ha^{-1} year^{-1}) and eroded soil mass (t ha^{-1} year^{-1}) was then predicted by

Figure 1. Projection of vegetation cover at each Erosion Research Plot

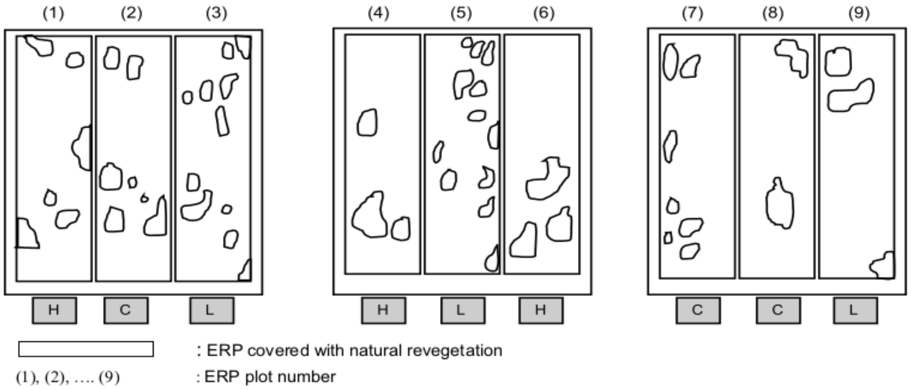
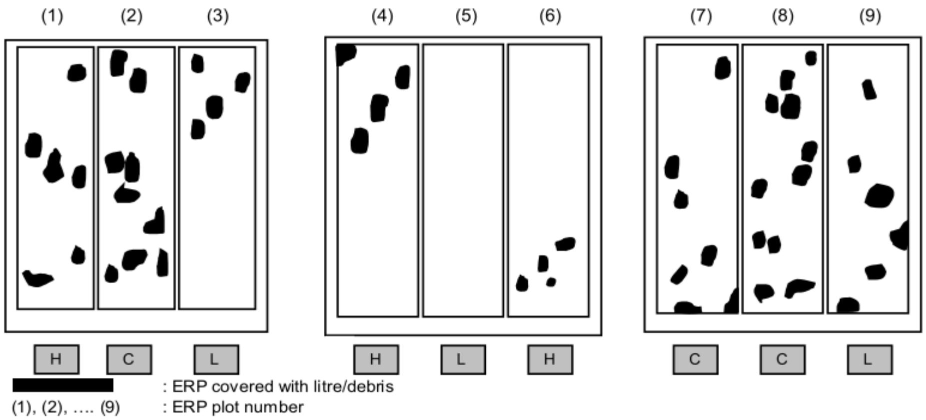


Figure 2. Projection of litter Cover at each Erosion Research Plot



extrapolating the original data collected for 4-5 months research period. The magnitude of predicted eroded soil mass was compared with the standard magnitude of permissible/acceptable/tolerable erosion rate to assess whether higher and/or lower viewed from considerable land productivity. Erosion of hazard class was found by comparing to the classification system of Class I (<15 t ha^{-1} year^{-1}), Class II (15-60 t ha^{-1} year^{-1}), Class III (60-180 t ha^{-1} year^{-1}), Class IV (180-480 t ha^{-1} year^{-1}), and Class V (>480 t ha^{-1} year^{-1}) respectively (Anonymous 1986, 1994). Erosion Hazard Level was assessed by combining of hazard erosion index and solum depth of soils as shown in Table 2.

RESULTS AND DISCUSSION

Soil erosion

In general, processes and soil erosion occurrences could be classified in sequential steps as soil aggregate detachment, soil particle dispersion, soils particle entrainment, and soil particle sedimentation. Field observation confirmed that these steps occurred. Rainfall mostly produced surface runoff in all research plots. These observations showed that forest logging followed by uncontrolled fires initiated surface runoff and soil erosion. However, the magnitude of soil erosion rate was still lower than the tolerable soil erosion rate.

Table 2. Classification of erosion hazard level

Erosion solum depth (cm)	Erosion hazard class				
	(I)	(II)	(III)	(IV)	(V)
	Erosion rates (t ha^{-1} year^{-1})				
	(<15)	(15~60)	(60~180)	(180~480)	(>480)
Depth (>90cm)	VL (0)	L (I)	M (II)	H (III)	VH (IV)
Moderate (60-90cm)	L (I)	M (II)	H (III)	VH (IV)	VH (IV)
Shallow (30-60cm)	M (II)	H (III)	VH (VI)	VH (IV)	VH (IV)
Very Shallow (<30 cm)	H (III)	VH (IV)	VH (IV)	VH (IV)	VH (IV)

VL: very light, L: light, m: moderate, H: heavy, VH: very heavy

As this research was not conducted immediately after forest fires, it is probable that the magnitude of eroded soil mass was lower than tolerable soil erosion rate. Most soil particles transported by surface runoff consisted of clay, silt and small amounts of sand. So it is assumed that organic materials or ash were mostly eroded before this research was conducted. It should be noted that surface runoff has a dominant role transporting dispersed soil particles. It was also very clear that a small amount of surface runoff sometimes transported soil particles only within the research plots and this before completely infiltrating the soil, and the next surface runoff would continue transportation of these eroded soil particles.

Dominant factors affecting soil erosion

Soil erosion processes and occurrences were simultaneously influenced by factors that work in a complex interaction with each other. Despite such complex interaction, it might be agreed that this interaction involves rainfall, soil erodibility, topography, vegetation cover and human activities. Among these factors, human activities are the most dominant factor influencing the increase of surface runoff and soil erosion and in this study logging activities caused the reduction of vegetation cover, allowing rain to impact directly on the forest floor. This phenomenon of rainfall causing soil aggregate detachment followed by soil particle dispersion was observed in the field. Soil compaction caused by logging activities directly reduced infiltration rate and capacity, and directly contributed to the increase of surface runoff when rainfall intensities were higher than infiltration capacities. Finally, the surface runoff following topography was potentially transporting dispersed soil particles to the various lower sites.

Total rainfall during 4 month period was 699 mm, other rainfall statistics are shown in Table 3. Surface runoff mostly occurred after the 40 rainfall events (Table 4).

Table 3. Rainfall amount and intensity during the research period (25 Oct. 1998-26 Feb. 1999)

Magnitude	Rainfall (mm)	Rainfall intensity (mm hour^{-1})
Total	699	
Mean	18	21
Minimum	1	2
Maximum	71	193

Note: data from 18 recorders at the edge of the research plots from 40 rainfall events.

Soil Erosion Characteristics

As a result of the rainfall in the observation period (Table 3) the volume of surface runoff was 993 litre ha^{-1} year^{-1} (heavy intensity), 1311 litre ha^{-1} year^{-1} (light intensity) and 1413 litre ha^{-1} year^{-1} (control) respectively (Table 4) These figures were compiled from direct measurement in the field and used to predict the eroded soil mass which was: 0.07 t ha^{-1} year^{-1} (heavy intensity), 0.05 t ha^{-1} year^{-1} (light intensity) and 0.06 t ha^{-1} year^{-1} (control) (Table 5).

To clarify the characteristics of the soil erosion process, possible relationships among factors influencing this process were analysed using a simple linear regression technique. The relationships were among rainfall amount, surface runoff (overland flow), and eroded soil mass (Table 6).

Table 4. Measurement of surface runoff/overland flow for each rainfall event

Magnitude	Surface runoff/overland flow					
	ERP(H)		ERP(L)		ERP(C)	
	(litre)	(litre ha^{-1}yr^{-1})	(litre)	(litre ha^{-1}yr^{-1})	(litre)	(litre ha^{-1}yr^{-1})
Total	2559	993	4711	1311	5122	1413
Mean	125	25	227	33	254	35
Minimum	0.5	0.1	0.5	0.2	0.5	0.2
Maximum	354	125	821	187	839	246

(H). Heavy logging or cutting intensity, (L). Light intensity, (C). Control.

Table 5. Eroded soil mass for each rainfall event

Magnitude	Eroded soil mass					
	ERP(H)		ERP(L)		ERP(C)	
	(g)	(t ha^{-1} year^{-1})	(g)	(t ha^{-1} year^{-1})	(g)	(t ha^{-1} year^{-1})
Total	243.5	0.073	151.8	0.046	201.4	0.060
Mean	6.1	0.001	3.8	0.001	5.0	0.002
Minimum	0	0	0.1	0	0.3	0
Maximum	31.5	0.009	21.7	0.007	19.4	0.006

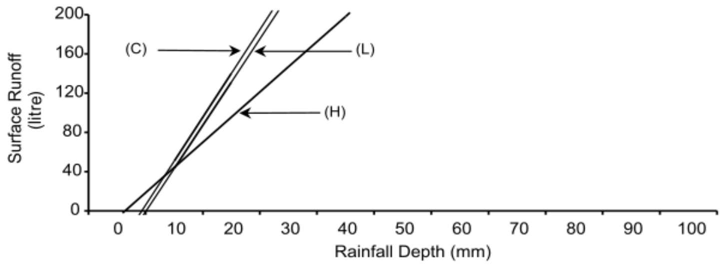
(H). Heavy logging or cutting intensity, (L). Light intensity, (C). Control.

Table 6. Correlations between rainfall amount, surface runoff (overland flow), and eroded soil mass at different logging intensities

Parameter	Erosion research plot	Regression equation	Correlation coefficient
Rainfall and surface runoff	(H)	$Y = 5.1296X - 6.9673$	0.78
	(L)	$Y = 8.7972X - 44.6030$	0.85
	(C)	$Y = 8.9477X - 38.7440$	0.72
Rainfall and eroded soil cover	(H)	$Y = 0.1992X + 2.5978$	0.26
	(L)	$Y = 0.0518X + 2.8893$	0.04
	(C)	$Y = 0.1086X + 3.1405$	0.14
Surface runoff and eroded soil cover	(H)	$Y = 0.0415X + 2.6477$	0.38
	(L)	$Y = 0.0062X + 3.1122$	0.05
	(C)	$Y = 0.0113X + 3.7136$	0.16

(H). Heavy logging or cutting intensity, (L). Light intensity, (C). Control.

Figure 4. Relationship between rainfall amount and surface runoff for each logging intensity in the erosion research plots



(H). Heavy logging or cutting intensity, (L). Light intensity, (C). Control.

High correlation coefficients (0.72-0.85) for rainfall and surface runoff indicate that the runoff increases with the amount of rainfall within a certain range (Table 6, Fig. 4) but there was little relationship between amount of rainfall and eroded soil cover, and surface runoff and eroded soil cover. This is generally found for the bare forest (bareland) under high rainfall with high intensity (Sudarmadji 1995).

Among the research plots, the control showed the highest surface runoff (5123 litres) compared with high intensity logging (2559 litres) and light intensity logging (4711 litres) treatments. It should be noted that the location of high intensity plots was a little steeper than others, and many tree parts remain inside the plots. Another reason was the wet soil condition caused by the previous rainfall occurrence. Fauzi (1996) and Fuliana (1996) reported that the interval between rainfall occurrences and vegetation remaining after logging strongly influence the magnitude of surface runoff. If there is a long interval between rainfall events, the soil condition will be drier than if rain occurs at shorter intervals and will favour greater infiltration rates and therefore less surface runoff. Conversely, if the interval was shorter while soil water was high, the magnitude of surface runoff would be greater.

In general, rainfall occurrences produce surface runoff transporting soil particles. However, raindrop impact does not always cause soil disaggregation, soil dispersion and soil erosion in the way as it is affected by previous conditions. High rainfall does not always produce more eroded soil mass than rainfall (Sudarmadji 1995). It is clear that the soil erosion is affected by several factors and occurs step by step depending on these factors.

The light intensity logging resulted in the least eroded soil mass compared to the others, possibly due to the remaining trees in the stand retarding surface runoff and soil erosion. The slope of this plot was less steep than in others. Surface runoff was an important factor influencing soil erosion. Referring to the relationship between rainfall amount and surface runoff and also eroded soil mass, the increase of rainfall tended to increase surface runoff (Gunawan 1996). However, increasing rates of eroded soil with the increase of surface runoff were different in the three treatments plots suggests that there were other strong factors such as lower soil erodibility, or not enough existing dispersed soil particles ready to be transported by surface runoff.

Magnitude of Soil Erosion and its Hazard Indices

Both soil erosion hazard class and index of soil erosion hazard level can be used as indicators to assess the impact of logging and forest fires on soil erosion rate and determine if it is higher or lower than tolerable/acceptable/permissible erosion rates. Each landscape has its own characteristics of soil erodibility and soil susceptibility and logging followed by forest fires would increase soil erodibility and soil susceptibility. Susceptibility refers to factors other than soil characteristics, such as slope, rainfall, etc., which influence the soil erosion events.

It is possible for assessment based on these indicators to be used as an important consideration for developing guidelines for implementation of logging activities. Further, such assessment could assist decision making on the need for soil erosion control measures and/or degraded land rehabilitation. Various soil erosion rates are frequently found in logged-over forest and an interpretation technique to assess them is urgently needed. The soil erosion hazard class and index of soil erosion hazard level offer a good solution. Classifying the measured magnitude of eroded soil mass into Classes I-V provides the basis for such assessment. Combining the soil erosion hazard class with its solum depth provides the index of hazard level soil erosion ranging from very light (VL) to very heavy (VH). The soil depth in study sites was very deep (>100cm), thus the assessment showed all treatments are very low soil erosion hazard index (Table 7) so measures to control erosion or improve the site are not urgent.

Table 7. Prediction of Eroded Soil Mass, Soil Erosion Hazard Class and Index of Soil Erosion Hazard Level

Logging intensities	Soil Erosion Magnitude ($t\ ha^{-1}\ year^{-1}$)	Soil Erosion Hazard Class	Index of Soil Erosion Hazard
High (dbh ≥30cm cutting)	0.07	I	VL
Light (dbh ≥50cm cutting)	0.05	I	VL
No logging (Control)	0.06	I	VL

Note: I = <15 $t\ ha^{-1}\ year^{-1}$, VL: very low

Minimising Impact of Logging and Forest Fire on Soil Erosion

Forest harvesting to extract commercial trees causes unavoidable impact, especially an increase of surface runoff and probably also of soil erosion rates. Hence, the most important question is whether forest harvesting followed by fires has brought about a serious threat to the sustainable forest land productivity. The answer will be very important in decisions as to whether erosion control measures and degraded land rehabilitation are needed. Such decisions have to be carefully examined due to the very high costs, time and manpower involved.

CONCLUSIONS

The most important conclusions of this research are:

- Both heavy and light intensity logging followed by uncontrolled forest fires increased surface runoff and in some cases also soil erosion rate.
- Increase of the amount of rainfall tended to increase surface runoff and therefore possibly increase eroded soil mass.
- Eroded soil mass did not always increase following increased surface runoff.
- Vegetation cover can retard surface runoff and soil erosion.
- The rate of soil erosion in logged-over forest lands (heavy, light and no logging intensities) followed by severe forest fire was still acceptable/tolerable/permissible, according to the research conducted 1.5 years after the logging and 6-10 months after the fire. Therefore, the land degradation risk is tolerable from a land productivity viewpoint and there is no immediate need for erosion control measures and land rehabilitation work.

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